

Comparison of Wired and Wireless Bio-Electrical Impedance Fluid Status Monitoring Devices
and Validation to Body Mass and Urine Specific Gravity Changes Following Mild Dehydration

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REPORT DOCUMENTATION PAGE				<i>Form Approved</i> <i>OMB No. 0704-0188</i>	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (12-12-2007) 01-18-08		2. REPORT TYPE Final		3. DATES COVERED 2007-2008	
Comparison of Wired and Wireless Bio-Electrical Impedance Fluid Status Monitoring Devices and Validation to Body Mass and Urine Specific Gravity Changes Following Mild Dehydration				5a. CONTRACT NUMBER USAFA/AD – USAFA/SGR MOA	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT	
6. AUTHOR(S) Brandon Doan, Michael Brothers, Mary Terry, Rebecca McLean, Eric Kozlowski, Al Wile				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) HQ USAFA/ADML 2169 Fieldhouse Drive USAFA, CO 80840				8. PERFORMING ORGANIZATION REPORT	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) USAF/SGR				10. SPONSOR/MONITOR'S ACRONYM(S) USAF/SGR	
				11. SPONSOR/MONITOR'S NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited					
13. SUPPLEMENTARY NOTES					
15. SUBJECT TERMS hydration status monitoring, bio-electrical impedance					
16. SECURITY CLASSIFICATION OF: UNCLASSIFIED			17. LIMITATION OF ABSTRACT UNLIMITED	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Lt Col Brandon Doan
a. REPORT UNCLASSIFIED	b. ABSTRACT UNCLASSIFIED	c. THIS PAGE UNCLASSIFIED			19b. TELEPHONE NUMBER (719)333-4188 DSN 333-4188

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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Summary

Background: Dehydration is a major health and performance risk in military operations and there is a need for rapid, non-invasive and early detection of hydration status changes. A fluid status assessment method, ZOE2, is FDA approved for fluid status monitoring in the clinical home healthcare environment. The ZOE2 measures thoracic bio-electrical impedance. A new wireless version of the ZOE2, the ZOE wireless (ZOEW), has been developed and proposed for assessment of fluid status in the field. Some investigations have reported impedance as a valid measure of hydration status in clinical or controlled settings (Higgins et al. 2007). However, there is speculation as to the utility of bio-electrical impedance post-exercise or in a field setting. (Koulmann et al. 2000; Casa et al. 2005). **Purpose:** The objectives of this study were fourfold: 1) to compare biological measurements of the new ZOEW monitor with the FDA approved and patented ZOE2 monitor currently being used in the healthcare market; 2) to assess the test-retest reliability of the ZOEW monitor; 3) to compare the sensitivity and validity of the ZOEW monitor and the ZOE2 monitor to assess mild hydration status changes post-exercise in a field setting; 4) to assess the usability of the ZOEW monitor. **Methods:** The research protocol was reviewed and approved by the USAF Academy Institutional Review Board on 7 Nov 07 (FAC2008007H). Thirty-two participants from the USAFA Wrestling Team were recruited. Written informed consent was obtained and confidentiality of data was kept. Nude body weight, urine specific gravity, ZOE2 and ZOEW measurements were taken before and after a typical 90-minute wrestling practice session. Usability was tested when participants were asked to complete a survey to assess perceptions of ease of use. **Results:** 1) Comparison of the two ZOE monitors from pre- to post-practice resulted in significant correlations: ZOE2 vs. ZOEW difference values ($r = 0.94$, $p < 0.001$), the pre-practice ZOE2 vs. ZOEW values ($r = 0.98$, $p < 0.001$), and the post-practice ZOE2 vs. ZOEW values ($r = 0.96$, $p < 0.001$). 2) Very high, positive test-retest correlations resulted for both devices indicating high reliability ($r = 0.95$ to 0.98 , $p < 0.001$). 3) Although both body weight and urine specific gravity changes were significantly ($p < 0.001$) different from pre- to post-practice indicating mild dehydration (body weight decreased 2.0% and urine specific gravity increased 0.3%), no significant differences were detected between pre- to post-practice for the ZOE2 ($p = 0.471$) or ZOEW ($p = 0.954$) device. 4) Copies of the surveys were given to NMT for analysis and reporting of usability data. **Conclusions:** Similar values were obtained from the ZOE2 and ZOEW monitors, indicating the monitors could be used interchangeably to assess the same biological variables. Test-retest reliability of the ZOE2 and ZOEW as assessed in this investigation was excellent. Bio-electrical impedance, as measured by the ZOEW monitor and the ZOE2 monitor in this study, does not appear to be a valid measure of mild, post-exercise hydration status change (2%) in a field environment as compared to body weight and urine specific gravity.

Introduction

Dehydration is a major health and performance risk to first responders, athletes or military personnel wearing protective clothing in physically demanding and/or heat stress environments and can lead to heat exhaustion and even heat stroke. Small losses in body water (as little as 1%) may result in cognitive (Lieberman 2007) and physical (Sawka 1988) performance decrements as well as thermoregulation problems (Sawka et al. 2001). Several methods for assessing dehydration have been studied: urine color, urine osmolality, urine specific gravity (USG), blood osmolality, body weight (BW), body water measurement through dilution, and bio-electrical impedance (Kavouras 2002; Carter et al. 2004; Casa et al. 2005; Cheuvront 2005).

Many of these fluid assessment criteria are often impractical, especially in home care or field environments. A fluid status assessment method, ZOE2, has been used, validated, and FDA approved for fluid status monitoring in the clinical home healthcare environment. The ZOE2 measures thoracic bio-electrical impedance, or Z_o , which is a measurement of the time it takes electric current to travel from the top to the bottom of the thorax. More fluid in the thorax should equate to less electrical resistance and vice versa (www.nmtinc.org). Therefore, the ZOE measurement may be an approximation of extra-cellular water (ECW) or circulating fluid volume. Peacock et al. verified an earlier study that $Z_o < 15$ ohms is equivalent to the amount of fluid seen as thoracic infiltrate on a chest x-ray (Peacock 2000). A new wireless version of the ZOE2, the ZOE wireless (ZOEW), has been developed and proposed for assessment of fluid status in the field.

Bio-electrical impedance has been evaluated as a measure of hydration status in clinical and healthy populations. Single-frequency bio-electrical impedance analysis (SF-BIA) has been validated as a method to measure total body water (TBW) (Hoffer et al. 1969) and ECW (Lukaski and Bolonchuk 1988). Bio-electrical spectroscopy (BIS) has also been validated as a measure of acute hydration status changes in healthy individuals (Koulmann et al. 2000; Higgins et al. 2007) and under certain clinical conditions (Ho et al. 1994; Matthie et al. 1998). Bio-electrical impedance measurements in these investigations, however, were conducted in controlled laboratory settings and were not immediately post-exercise.

Several authors report that bio-electrical impedance is not a valid field measure of hydration status changes (Carter et al. 2004; Casa et al. 2005; Cheuvront 2005). Notably, the American College of Sports Medicine published a “Consensus Statement” in 2005 that reported, “Bioelectric impedance can provide an indication of total body water, but is a poor indicator of hydration status or of changes in hydration status (Casa et al., 2005)”. Fluid and electrolyte shifts occur during and immediately following exercise which effect post-exercise bio-electrical impedance measurements (Koulmann et al. 2000). Additionally, many of the sources of error associated with bio-electrical impedance measurement that can be controlled in a clinical or laboratory setting may not be controllable in a field setting such as: posture, limb position, ambient temperature, hydration status, food and liquid intake, fluid shifts, sweating, and recency of exercise (Caton et al. 1988; Roos et al. 1992; Shirreffs and Maughan 1994; Gudivaka et al. 1996; Armstrong et al. 1997; Cheuvront 2005).

The objectives of this study were fourfold: 1) to compare biological measurements of the new ZOEW monitor with the FDA approved and patented ZOE2 monitor currently being used in the healthcare market; 2) to assess the test-retest reliability of the ZOEW monitor; 3) to compare the sensitivity and validity of the ZOEW monitor and the ZOE2 monitor to assess

mild hydration status changes post-exercise in a field setting as compared to USG and BW; 4) to assess the usability of the ZOEW monitor.

Methods

This study was a correlational, repeated measures design to evaluate the accuracy, validity, repeatability, and usability of a new wireless bio-electrical impedance hydration monitor. Thirty two male members of the USAF Academy (USAFA) Wrestling Team were recruited for this study. Recruiting was accomplished through a briefing with the wrestling team. Those volunteers who met the study qualifications (no hypersensitive skin) completed all data collection at the USAFA Cadet Gymnasium. All participants attended a study information meeting where they were briefed on the important elements of the protocol and read the informed consent document (ICD), which was approved by the USAFA Institutional Review Board on 7 Nov 07 (FAC2008007H). After each participant read the ICD, had all questions answered and agreed to all the conditions, the participant signed the ICD. Additionally, this study was discussed with the USAFA Wrestling Coach and he was in concurrence with all procedures and agreed not to punish or reward team members for participation or non-participation.

Statistical Analyses. SPSS (version 14.0) statistical analysis software was used for all statistical analyses. When testing at the 0.05 two-tailed alpha level, a sample size of 28 participants will provide approximately an 80% chance (power) of detecting a small to moderate (0.3 to 0.5) correlation between the ZOEW and ZOE2. For the repeated measures ANOVA to compare pre- and post-practice hydration status measurements, a sample size of 28 participants will provide approximately an 86% to 99% chance of detecting a small to moderate effect size (Cohen 1988).

Experimental Procedures.

Pre- Post-Practice hydration measures.

Hydration measurements were taken immediately before and immediately after a 90-minute NCAA Division I wrestling practice.

Bio-electrical Impedance. The ZOE2 and ZOEW measure thoracic impedance which is a measurement of the time it takes electric current to travel from the top to the bottom of the thorax. More fluid in the thorax should equate to less electrical resistance and vice versa (www.nmtinc.org). Therefore, the ZOE measurement may be an approximation of ECW or circulating fluid volume (Peacock 2000).

Participants were provided written and verbal instructions on how to properly attach electrodes and use ZOE2 and ZOEW devices. Additionally, one of the research assistants displayed the electrodes properly attached to their own thorax to provide a visual reference for the participants.

Table 1: Summary of ZOE instructions provided to participants

The skin must be thoroughly cleaned before placing the electrode(s) to assure a good connection to the skin and a good Zo measurement.
All hair should be removed/shaved from the site where the electrode(s) will be placed to assure good connection to the skin
Prep the area with an alcohol wipe, followed by drying with a gauze pad, to remove any excess skin oils
The superior impedance electrode can be placed midline on the throat or to either side of the throat
The inferior impedance electrode must be placed at the level of the xyphoid process.

The electrodes were then connected by a cable to the ZOE2 and three separate measurements were taken and written down by the participant on a data sheet and verified by a research assistant. The electrode cable was disconnected from the ZOE2 and connected to the ZOEW. The ZOEW was then activated and three separate measurements for each participant were taken and written down by the participant on a data sheet and verified by a research assistant. The electrodes were left on the wrestlers during practice and the electrode cables were labeled and stored to ensure the same cables were used by the same participants after practice.

Following wrestling practice, a research assistant recorded how many electrodes required replacement and whether the electrodes were voluntarily removed or were knocked off or damaged due to incidental contact and sweating during practice. If electrodes came off, participants were instructed to again follow the skin preparation and electrode placement instructions outlined in Table 1. The participant was then given their electrode cable to attach to the electrodes and the same procedures used for pre-practice ZOE2 and ZOEW measurement were repeated.

Post-practice ZOE2 and ZOEW measurements were subtracted from the pre-practice ZOE2 and ZOEW measurements to determine changes or difference values.

Body weight. The difference in pre- and post-activity body weight is a reasonable estimate of acute body water losses due to exercise or heat stress (Earthman et al. 2000; Casa et al. 2005; Higgins et al. 2007). In this investigation, participants were weighed without any clothes on before and after the wrestling practice on the same calibrated scale (Befour Model No. PS6600, Befour, Inc., Saukville, WI). Post-practice weight was subtracted from the pre-practice weight to determine BW change or difference values.

Urine specific gravity. USG has been reported as a valid marker for hydration status changes (Armstrong et al. 1998; Popowski et al. 2001; Shirreffs 2003). In this current investigation, USG was analyzed by the wrestling team's Certified Athletic Trainer who has been trained in this type of analysis and does it regularly for the NCAA certification of the wrestling team. Urine was collected from each wrestler both pre- and post-practice in a clean urine specimen cup. Six drops of urine were placed on a refractometer to measure specific gravity. The refractometer used for analysis of USG was an ATAGO Digital Urine Specific Gravity

Refractometer UG-1 Cat. No. 3461 (Bellevue, WA). Prior to the pre- and post-practice measurement, the refractometer was calibrated with distilled water. Post-practice USG measurements were subtracted from the pre-practice USG measurements to determine changes or difference values.

Water Intake. Because this was an actual wrestling practice and many of the wrestlers had a competition the following day, participants were not restricted from drinking water. Participants were asked, immediately following practice, to estimate in ounces how much water they consumed.

Usability of ZOEW Monitor. Usability measured in a user survey will use descriptive statistics to evaluate subject perception responses to Likert scale questions.

Results

Thirty-one participants completed the study. Thirty-two participants signed ICD's; however, only 31 participants showed up for data collection. See Table 5 for raw data. Note that there is not a participant number 7. He signed the ICD, but did not show up for data collection. Due to the usual problems associated with data collection, a very small amount of data was lost. One participant missed the body weight and urine specific gravity data collection. One participant could only obtain one of three pre-practice measurements on the ZOE2. Another participant wrote an illegible value for his third pre-practice ZOE2 measurement and one participant wrote an illegible value for his first post-practice ZOEW measurement. One outlier for the pre-practice ZOE2 measurement was identified, for participant #19, not included in statistical analysis. The reason for this outlier is unknown, but may be related to electrode preparation or placement. One outlier for the post-practice USG measurement was identified, for participant #5, and not included in statistical analysis. The reason for this outlier is also unknown. The refractometer was recalibrated after this measurement. Prior to analysis, missing data points were excluded case wise. Any mention of statistical significance refers to an alpha level of .05.

Appendix A (Table 5) is a summary table of the raw data. In the text below, a general description of the results for key variables are provided, followed by detailed discussion and graphs of selected measures.

1) Comparison of the ZOE2 and ZOEW Devices

Comparison of the two ZOE monitors from pre- to post-practice resulted in significant and positive correlations: ZOE2 difference values and ZOEW difference values ($r = 0.94$, $p < 0.001$), the pre-practice ZOE2 and ZOEW values ($r = 0.98$, $p < 0.001$), and the post-practice ZOE2 and ZOEW values ($r = 0.96$, $p < 0.001$).

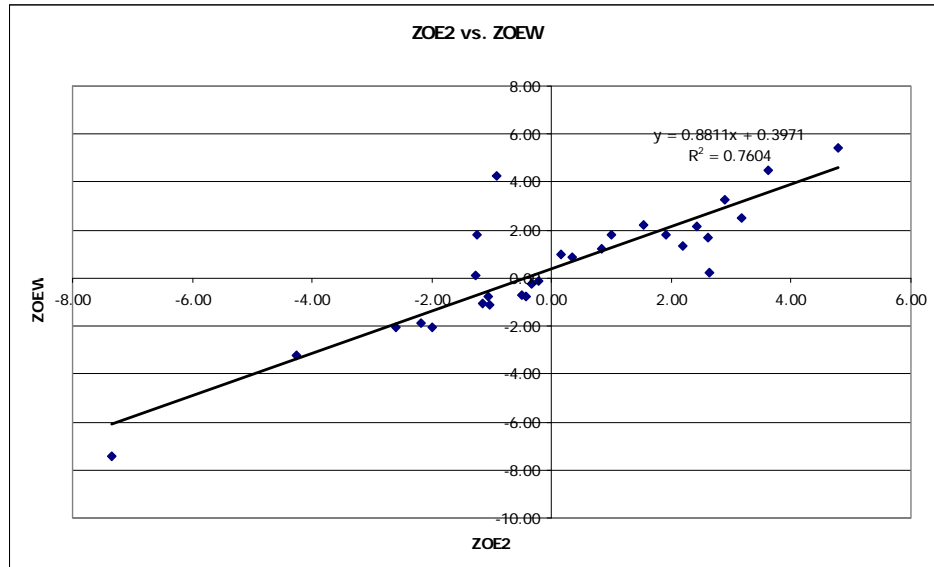


Figure 1: Pre-post practice ZOE2 difference plotted against pre-post practice ZOEW difference

In addition to Pearson product moment correlations, a repeated measures ANOVA was used to statistically compare ZOE2 and ZOEW differences (Figure 2). No significant difference ($p = 0.229$) was detected between measures.

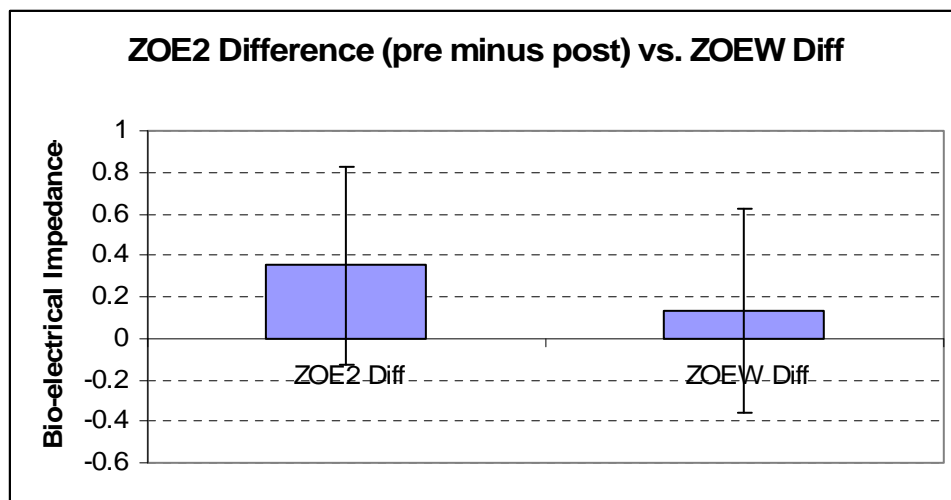


Figure 2: Comparison of ZOE2 and ZOEW difference (values are mean difference – pre minus post \pm SE). No significant difference ($p = 0.229$)

2) Test-Retest Reliability of the ZOE2 and ZOEW.

The test-retest reliability of both ZOE devices was estimated by performing repeated measures with the same device and same participants at the same time point. The correlation coefficient between such measures is one method for quantifying test-retest reliability. Pearson correlations were computed for the three pre-practice and three post-practice measures for each device (Table 2). Statistically significant, high, and positive correlations resulted for both devices indicating good test-retest reliability.

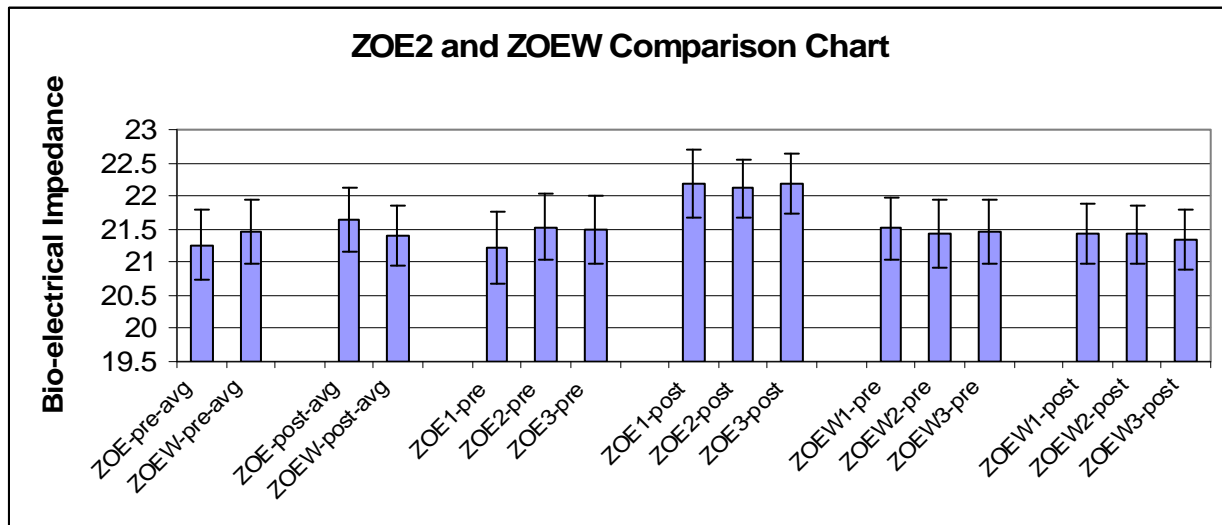
Table 2: Summary of Test-Retest Reliability between repeated ZOE2 and ZOEW Measures (Pearson Correlation (R))

	ZOE1-pre	ZOE2-pre		ZOE1-post	ZOE2-post
ZOE2-pre	0.98**		ZOE2-post	0.95**	
ZOE3-pre	0.97**	0.98**	ZOE3-post	0.95**	0.97**

	ZOEW1-pre	ZOEW2-pre		ZOEW1-post	ZOEW2-post
ZOEW2-pre	0.97**		ZOEW2-post	0.96**	
ZOEW3-pre	0.98**	0.98**	ZOEW3-post	0.96**	0.97**

** Correlation is significant at the 0.01 level (2-tailed).

To further evaluate the test-retest reliability of the devices, a repeated measures ANOVA was used to compare the means of each device at each time point (Figure 3, Table 3). No significant differences were detected when comparing average measurements from each device at each time point.



**Figure 3: Comparison - ZOE2 and ZOEW Means (values are means ±SE)
No significant differences between clustered groups**

Table 3: Summary of Means for ZOE2 and ZOEW Measures

	Mean	Std. Error
ZOE-pre-avg	21.26	0.53
ZOEW-pre-avg	21.47	0.48
ZOE-post-avg	21.65	0.49
ZOEW-post-avg	21.40	0.44
ZOE1-pre	21.21	0.54
ZOE2-pre	21.53	0.49
ZOE3-pre	21.49	0.50
ZOE1-post	22.18	0.51
ZOE2-post	22.11	0.45
ZOE3-post	22.18	0.46
ZOEW1-pre	21.51	0.46
ZOEW2-pre	21.43	0.51
ZOEW3-pre	21.46	0.48
ZOEW1-post	21.43	0.46
ZOEW2-post	21.42	0.44
ZOEW3-post	21.35	0.45

No significant differences between clustered groups

3) Pre- post-practice comparisons of hydration measures

Table 4 below summarizes comparisons between pre- and post-practice hydration measures. Pre- post-practice hydration measure means were compared using repeated measures ANOVA. The sample size was 28 for the BW, 27 for the USG comparison, and 28 for ZOE comparisons due to previously mentioned outliers and missing data for participant #32. Also, data for participants #30 and #31 were not included in this analysis because they did not participate in the same practice session as the rest of the team.

56 of the 62 electrodes had to be replaced after wrestling practice. Forty eight of the electrodes fell off or were damaged due to incidental contact and sweating during practice. Eight electrodes were voluntarily removed by the participants because the electrodes were bothering them during practice.

Table 4: Summary of Pre- Post-Practice Comparisons

Variable	Mean	Std. Dev	Std. Error	p-value
*BW-pre	167.5	23.9	4.5	0.000
*BW-post	164.0	23.7	4.5	
*USG-pre	1.021	0.008	0.002	0.001
*USG-post	1.024	0.005	0.001	
ZOE-pre-avg	21.26	2.56	0.53	0.471
ZOE-post-avg	21.65	2.62	0.49	
ZOEW-pre-avg	21.05	2.90	0.54	0.954
ZOEW-post-avg	21.08	2.53	0.47	

* significant difference between pre- and post-practice ($p \leq .05$)

Body Weight

For the nude body weight measure, a significant difference was detected between pre- and post-practice measures. The wrestlers lost an average of 3.5 pounds (2.04%) during the 90 minute wrestling practice (Figure 4).

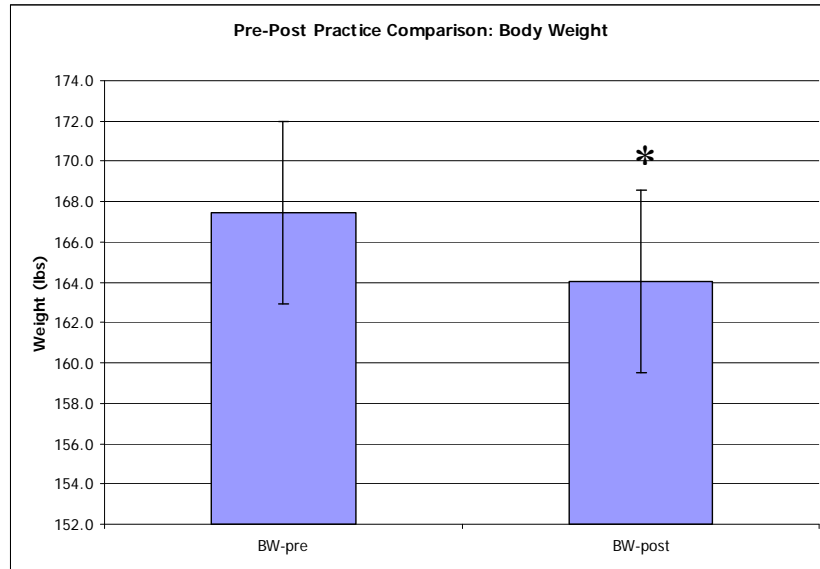


Figure 4: Pre-Post Practice Comparison: Body Weight (values are means \pm SE)
 * significant difference between pre- and post-practice ($p = 0.000$)

Urine Specific Gravity

For the USG measure, a significant difference was detected between pre- and post-practice measures. The wrestlers' USG increased from 1.021 to 1.024 (0.27%) during the 90 minute wrestling practice (Figure 5).

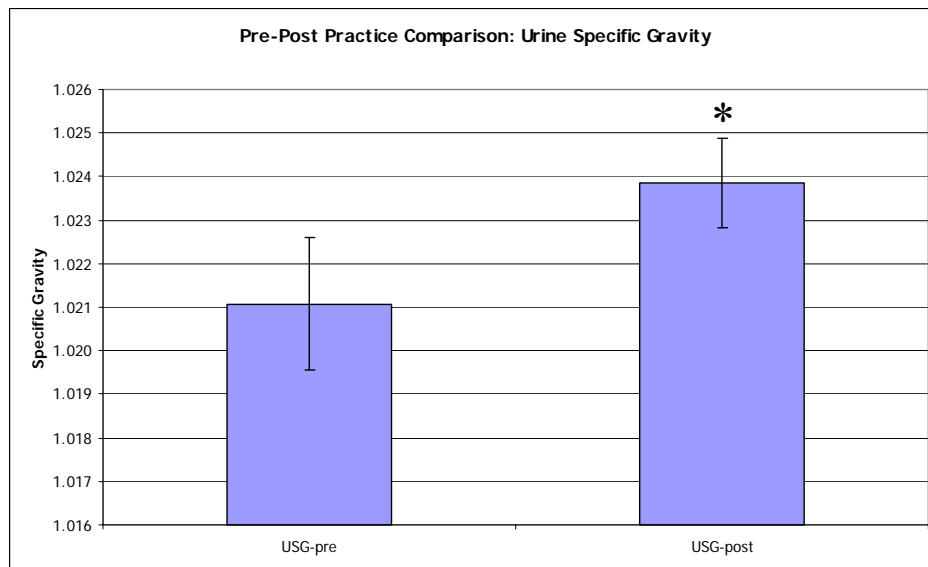


Figure 5: Pre-Post Practice Comparison: Urine Specific Gravity (values are means \pm SE)
 * significant difference between pre- and post-practice ($p = 0.001$)

ZOE2

For the ZOE2 measure, no significant difference was detected between pre- and post-practice measures. On average, the wrestlers' ZOE2 measurements increased from 21.26 to 21.65 (1.8%) during the 90 minute wrestling practice (Figure 6).

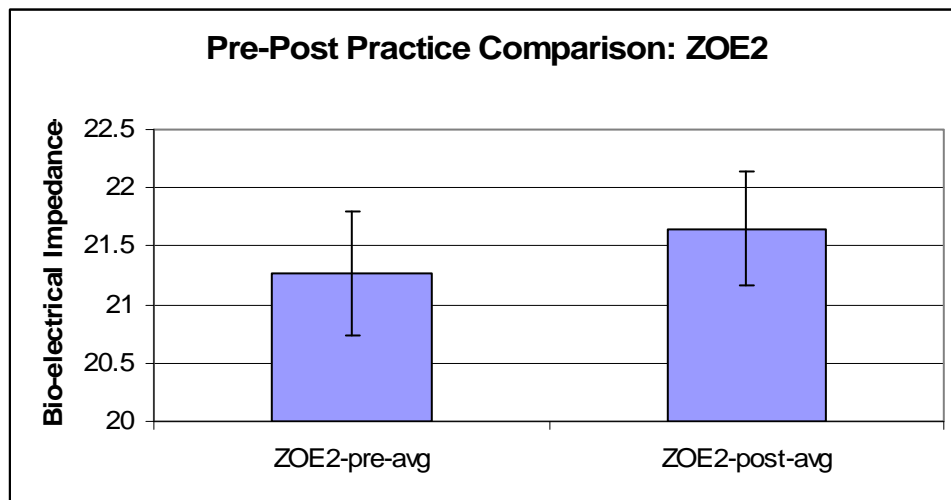


Figure 6: Pre-Post Practice Comparison: ZOE2 (values are means \pm SE)
No significant difference between pre- and post-practice ($p=0.471$)

ZOEW

For the ZOEW measure, no significant difference was detected between pre- and post-practice measures. On average, the wrestlers' ZOEW measurements increased from 21.05 to 21.08 (0.13%) during the 90 minute wrestling practice (Figure 7).

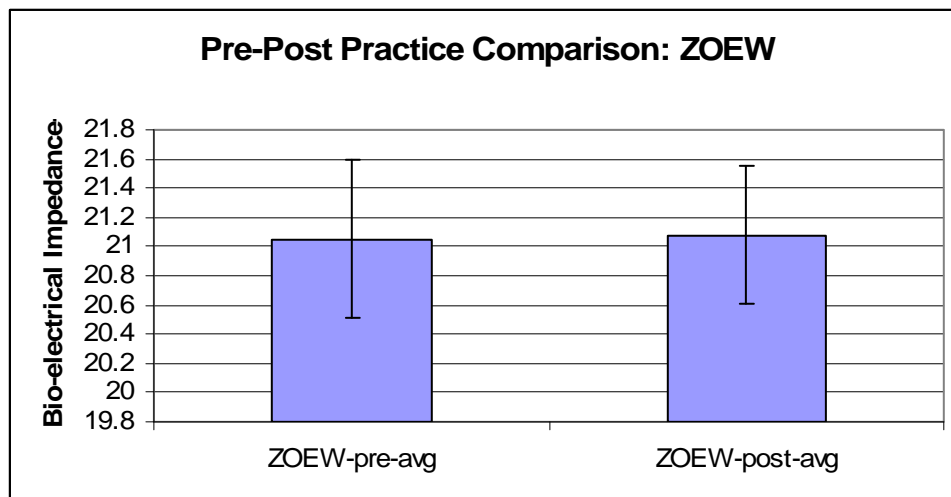


Figure 7: Pre-Post Practice Comparison: ZOEW (values are means \pm SE)
No significant difference between pre- and post-practice ($p=0.954$)

Graphical Representation of Pre- Post-Practice Hydration Measure Individual Differences by Participant: Following are graphical representations of the hydration measure pre-post practice differences. The purpose of these graphs is to display the individual variability and direction of change for each measure. All 28 participants decreased in BW from pre- to post-practice (Figure 9). 20 of 28 participants' USG increased from pre- to post-practice, 3 stayed the same, and 5 decreased (Figure 10). 16 participants' ZOE2 values increased from pre- to post-practice and 13

decreased (Figure 11). 14 participants' ZOEW values increased from pre- to post-practice and 15 decreased (Figure 11).

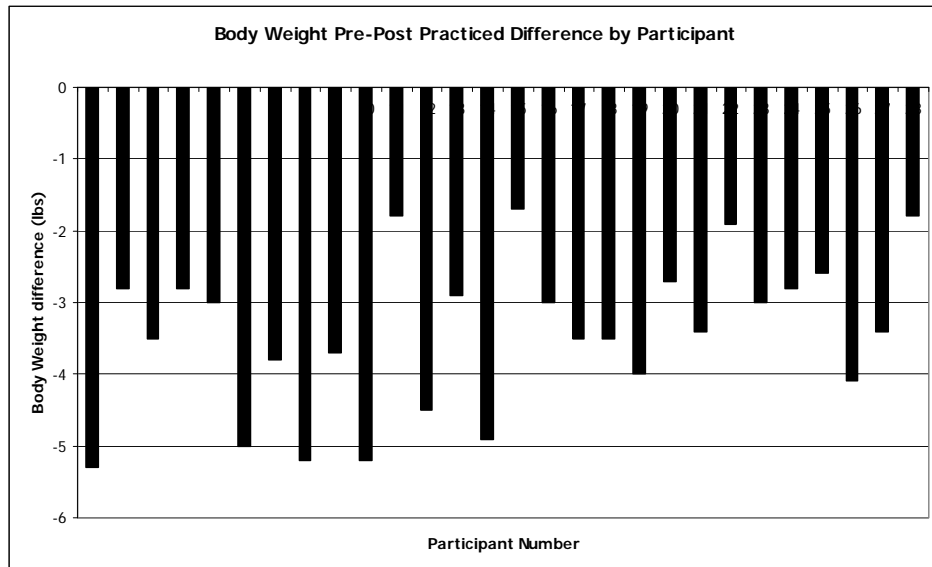


Figure 9: Body Weight Pre-Post Practice Difference by Participant

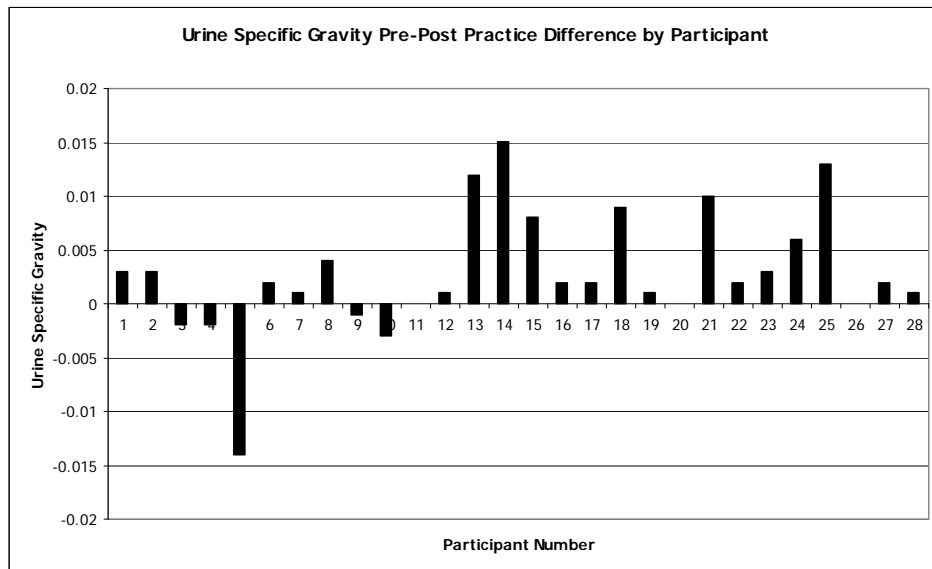


Figure 10: USG Pre-Post Practice Difference by Participant

Note: Participant #5 in this graph was an outlier and was not included in statistical analysis

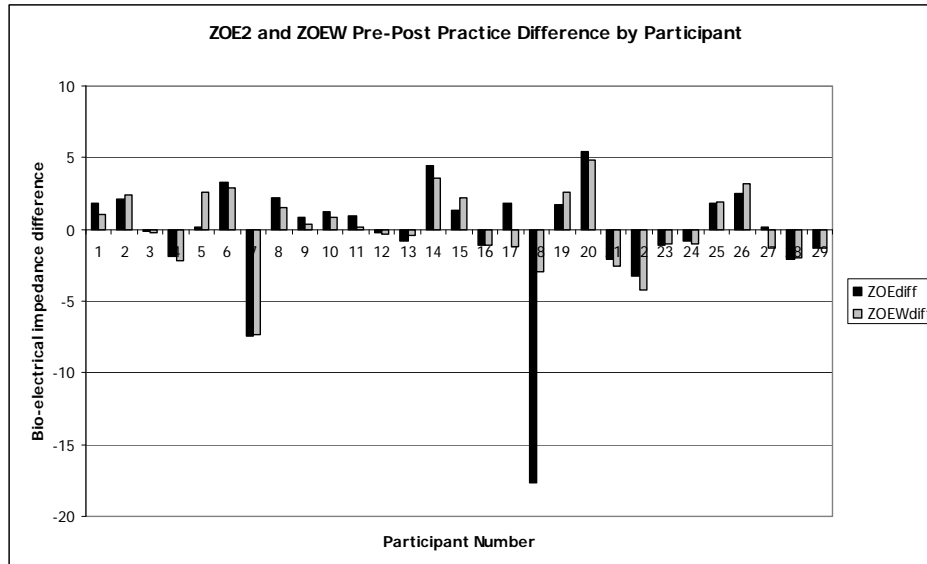


Figure 11: ZOE2 and ZOEW Pre-Post Practice Difference by Participant

Note: Participant #18 in this graph was an outlier for the ZOE2 measurements and was not included in statistical analysis

4) Usability of ZOEW Monitor

Usability surveys were completed by the participants. Copies of the surveys were given to NMT for analysis and reporting.

Discussion

The objectives of this study were fourfold: 1) to compare biological measurements of the new ZOEW monitor with the FDA approved and patented ZOE2 monitor currently being used in the healthcare market; 2) to assess the test-retest reliability of the ZOEW monitor; 3) to compare the sensitivity and validity of the ZOEW monitor and the ZOE2 monitor to assess mild hydration status changes post-exercise in a field setting as compared to USG and BW; 4) to assess the usability of the ZOEW monitor.

1) Comparison of the ZOE2 and ZOEW Devices

Based on the results of this investigation, the comparison of the new ZOEW monitor with the FDA approved and patented ZOE2 monitor were favorable. Similar values were obtained from the ZOE2 and ZOEW monitors, indicating the monitors could be used interchangeably to assess the same biological variables. Comparison of the two ZOE monitors from pre- to post-practice resulted in significant correlations and a repeated measures ANOVA was used to statistically compare ZOE2 and ZOEW differences and no significant difference was detected between measures.

2) Test-Retest Reliability of the ZOE2 and ZOEW

Significant, very high, positive correlations resulted for both devices indicating excellent test-retest reliability. To further evaluate the test-retest reliability of the devices, a repeated measures ANOVA was used to compare the means of each device at each time point. No significant

differences were detected. Previous researchers have also reported good reliability for bio-electrical impedance measures (Shanholtzer and Patterson 2003).

3) Pre- post-practice comparisons of hydration measures

Body weight decreased by 3.5 pounds (2.04%) and USG increased 1.021 to 1.024 (0.27%) during the 90 minute wrestling practice, indicating mild dehydration. Both of these differences were statistically significant ($p < 0.001$) and similar to previous findings (Koulmann et al. 2000; Stover et al. 2006). ZOE2 and ZOEW measurements, however, were not statistically different from pre- to post-practice. Although, the means of both devices slightly increased from pre- to post-practice, indicating increased impedance and dehydration, the variation of the difference measurements was high relative to the differences in the means. On average, the wrestlers' ZOE2 measurements increased from 21.26 to 21.65 ohms (1.8%), while standard deviation of the difference (0.35 ohms) was ± 2.53 ohms. ZOEW measurements increased from 21.05 to 21.08 (0.13%) while standard deviation of the difference (0.03 ohms) was ± 2.62 ohms. The individual variability and direction of change for each measure clearly further elucidates this high variation. 16 participants' ZOE2 values increased from pre- to post-practice and 13 decreased, while 14 participants' ZOEW values increased from pre- to post-practice and 15 decreased (Figure 11). Similar to several previous investigations, our findings indicate that bio-electrical impedance as used in this study is not a valid measure of post-exercise mild dehydration in a field environment (Armstrong et al. 1997; O'Brien et al. 1999; Koulmann et al. 2000; O'Brien et al. 2002; Carter et al. 2004; Casa et al. 2005; Cheuvront 2005).

Many investigators have reported factors that may effect bio-electrical impedance measurements: electrode placement, side of body, posture, limb position, ambient temperature, skin temperature, hydration status, food and liquid intake, fluid shifts, sweating, and recency of exercise (Caton et al. 1988; Roos et al. 1992; Shirreffs and Maughan 1994; Gudivaka et al. 1996; Armstrong et al. 1997; Cheuvront 2005). In this current study, ambient temperature could not have been an error source because it did not change from pre- to post-practice measurements. Skin was cleaned and dried prior to reapplication of the electrodes, so this may have reduced or eliminated errors due to sweating.

In this current study specifically, some of the potential error in the impedance measurements could have been due to posture and limb position, skin temperature, electrode placement, fluid intake, and recency of exercise. Although posture and limb position were similar (both standing) from pre- to post-practice measurements, participants were not supine with controlled limb positions as in most previous studies that have reported valid impedance measurements as related to body water or hydration status assessment. Skin temperature could have also been a source of error as it was not controlled and could have changed due to thermoregulation and friction during wrestling practice.

In this study, electrodes were placed by participants. Participants were given specific instructions on where to place electrodes; however, 56 of the 62 electrodes had to be replaced after wrestling practice. Forty eight of the electrodes fell off or were damaged due to incidental contact and sweating during practice. Eight electrodes were voluntarily removed by the participants because the electrodes were bothering them during practice. Electrode replacement should have been close to the original electrode placement as the participants were instructed to replace the electrodes on the same anatomical markers and placement was verified by a research assistant. However, if we had anticipated the majority of the electrodes coming off during practice we could have physically marked or measured the location of the original electrode

placement to ensure exact replication. Although these electrode adhesion problems could have contributed to potential measurement errors, the data may also indicate the need to specifically evaluate or improve electrodes for operational conditions.

Because this was an actual wrestling practice and many of the wrestlers had a competition the following day, participants were not restricted from drinking water. Participants were asked, immediately following practice, to estimate in ounces how much water they consumed and reported drinking an average of 9.09 ounces of water during the 90-minute practice session. This amount of fluid ingestion should not have affected the bio-electrical impedance measures because the electrodes were limited to the thorax and the water would be in the stomach or absorbed into TBW. Additionally, the water ingestion would have also affected the BW measures, which clearly indicated dehydration.

As this investigation was a field validation of the use of the ZOE and ZOEW devices to assess hydration change in simulated “operational” conditions, many of these variables were purposefully not controlled as control would not be possible in an “operational” military environment. Additionally, a similar study very tightly controlled the aforementioned potential error sources and waited two hours after exercise and still reported that bio-electrical impedance only accounted for half of the TBW loss (Koulmann et al. 2000). Fluid shifts were the proposed mechanism for the erroneous measurements.

Conclusions

Similar values were obtained from the ZOE2 and ZOEW monitors, indicating the monitors could be used interchangeably to assess the same biological variables. Test-retest reliability of the ZOE2 and ZOEW was excellent. However, based on the results of this investigation, bio-electrical impedance, as measured by the ZOEW monitor and the ZOE2 monitor do not appear to be valid measures of post-exercise mild hydration status changes (2%) as used in this study and compared to BW and USG in a simulated “operational” or field environment. Further research is required to assess potential sources of error in the use of these devices to monitor hydration status changes. However, previous researches have implemented tighter controls and still report bio-electrical impedance as an invalid measurement of hydration status following exercise or in a field environment.

Recommendations

Based on the results of this investigation and review of related scientific literature, bio-electrical impedance in any current form is not a valid assessment of post-exercise hydration status change in a field environment when strict controls are not possible. ZOE2 or ZOEW should not be fielded in their current state to assess post-exercise hydration status changes of humans in a military “operational” environment.

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Participant	Weight-pre (lbs)	Weight-post (lbs)	Weight-diff (lbs)	USG-pre	USG-post	USG-diff	ZOE-pre-avg	ZOE-post-avg	ZOE-diff	ZOEw-pre-avg	ZOEw-post-avg	ZOEw-diff	ZOE1-pre	ZOE2-pre	ZOE3-pre	ZOEw1-pre	ZOEw2-pre	ZOEw3-pre	ZOE1-post	ZOE2-post	ZOE3-post	ZOEw1-post	ZOEw2-post	ZOEw3-post	Water (oz)
1	142.8	137.5	-5.3	1.026	1.029	0.003	21.50	23.33	1.83	22.02	23.02	1.00	21.10	21.40	22.00	21.89	21.91	22.26	23.10	23.70	23.20	23.06	23.17	22.83	5
2	189.7	186.9	-2.8	1.023	1.026	0.003	20.57	22.70	2.13	20.58	23.01	2.43	21.20	20.40	20.10	20.94	20.15	20.64	23.00	22.20	22.90	23.15	23.29	22.59	12
3	128.4	124.9	-3.5	1.023	1.021	-0.002	23.40	23.30	-0.10	22.55	22.34	-0.21	23.80	23.50	22.90	22.79	22.38	22.47	23.90	23.10	22.90	22.49	22.15	22.37	0
4	150.4	147.6	-2.8	1.033	1.031	-0.002	25.53	23.63	-1.90	25.82	23.64	-2.18	25.30	25.40	25.90	25.55	26.20	25.70	23.40	23.80	23.70	23.22	23.85	23.84	2
5	193.6	190.6	-3	1.024	1.01	-0.014	15.10	15.30	0.20	13.33	15.96	2.64	15.10			14.31	11.76	13.91	15.30	15.30		16.29	15.80	15.80	8
6	181	176	-5	1.025	1.027	0.002	19.27	22.53	3.27	18.83	21.72	2.89	19.20	19.50	19.10	18.64	18.49	19.37	21.90	22.60	23.10	21.43	22.27	21.47	2
8	139.8	136	-3.8	1.018	1.019	0.001	27.77	20.37	-7.40	26.54	19.20	-7.35	27.80	28.10	27.40	26.15	26.58	26.90	20.10	20.40	20.60	19.85	19.59	18.15	6
9	173.2	168	-5.2	1.022	1.026	0.004	21.37	23.57	2.20	21.30	22.84	1.54	21.80	21.10	21.20	21.51	21.45	20.94	23.80	23.40	23.50	23.11	22.51	22.91	3
10	156.1	152.4	-3.7	1.03	1.029	-0.001	24.20	25.07	0.87	23.58	23.92	0.34	23.70	24.00	24.90	23.58	23.71	23.45	25.50	24.80	24.90	23.88	23.83	24.06	10
11	175.4	170.2	-5.2	1.024	1.021	-0.003	20.23	21.47	1.23	20.00	20.84	0.84	19.80	20.60	20.30	19.98	19.74	20.27	21.80	21.00	21.60	20.81	20.55	21.16	1
12	142.6	140.8	-1.8	1.026	1.026	0	24.77	25.73	0.97	23.83	23.98	0.15	24.70	24.90	24.70	23.97	24.18	23.35	25.50	25.90	25.80	24.28	23.87	23.79	20
13	149.3	144.8	-4.5	1.026	1.027	0.001	18.53	18.27	-0.27	18.04	17.70	-0.34	18.30	19.20	18.10	18.26	18.01	17.86	17.50	19.30	18.00	18.25	17.66	17.19	24
14	181.1	178.2	-2.9	1.011	1.023	0.012	18.63	17.87	-0.77	18.08	17.66	-0.42	18.80	18.60	18.50	18.29	17.60	18.36	17.70	17.80	18.10	17.69	17.30	17.99	2
15	223.8	218.9	-4.9	1.011	1.026	0.015	18.50	22.97	4.47	18.16	21.78	3.62	18.40	18.10	19.00	17.92	18.65	17.91	23.60	22.30	23.00	22.99	21.59	20.76	0
16	126.3	124.6	-1.7	1.003	1.011	0.008	23.80	25.13	1.33	23.27	25.46	2.19	23.70	24.20	23.50	23.53	23.64	22.64	25.70	24.80	24.90	25.03	25.54	25.82	8
17	172.3	169.3	-3	1.02	1.022	0.002	22.17	21.10	-1.07	22.34	21.20	-1.15	22.10	22.30	22.10	22.32	22.34	22.37	21.20	20.50	21.60	21.05	21.30	21.24	0
18	196.6	193.1	-3.5	1.023	1.025	0.002	20.63	22.43	1.80	20.67	19.42	-1.24	20.50	20.60	20.80	20.87	20.40	20.73	21.20	22.50	23.60	19.62	19.54	19.11	10
19	163.3	159.8	-3.5	1.015	1.024	0.009	40.33	22.63	-17.7	24.71	21.76	-2.95	40.10	42.10	38.80	24.30	25.63	24.20	22.70	22.90	22.30	22.57	21.00	21.70	6
20	164.8	160.8	-4	1.028	1.029	0.001	20.40	22.10	1.70	20.23	22.84	2.61	20.50	20.40	20.30	20.37	20.15	20.17	22.60	21.50	22.20	22.42	22.85	23.25	14
21	138.7	136	-2.7	1.031	1.031	0	18.83	24.27	5.43	18.92	23.71	4.79	17.80	19.10	19.60	18.68	18.65	19.43	24.20	24.40	24.20	23.45	24.41	23.28	20
22	158.1	154.7	-3.4	1.004	1.014	0.01	18.73	16.67	-2.07	19.42	16.81	-2.61	19.20	18.30	18.70	20.31	19.08	18.87	16.40	17.00	16.60	16.33	16.74	17.37	5
23	145.3	143.4	-1.9	1.025	1.027	0.002	20.77	17.53	-3.23	20.65	16.39	-4.26	20.60	20.90	20.80	20.25	20.89	20.82	17.30	17.80	17.50	15.82	17.00	16.35	24
24	179.5	176.5	-3	1.021	1.024	0.003	23.27	22.13	-1.13	22.47	21.44	-1.03	23.50	23.20	23.10	22.48	22.40	22.54	21.90	22.40	22.10	21.85	21.39	21.09	8
25	194.9	192.1	-2.8	1.015	1.021	0.006	23.60	22.83	-0.77	23.10	22.05	-1.05	23.60	23.30	23.90	24.34	22.07	22.90	23.70	22.80	22.00	22.14	22.02	21.99	24
26	202.3	199.7	-2.6	1.005	1.018	0.013	21.83	23.67	1.83	21.30	23.22	1.92	21.90	21.80	21.80	21.11	21.45	21.33	23.50	23.80	23.70	23.07	23.43	23.15	20
27	173.2	169.1	-4.1	1.027	1.027	0	16.33	18.83	2.50	15.37	18.53	3.16	15.70	17.00	16.30	15.64	15.46	15.00	18.90	18.70	18.90	18.31	18.75	18.53	8
28	181.3	177.9	-3.4	1.023	1.025	0.002	19.83	19.97	0.13	20.24	18.97	-1.28	20.40	19.80	19.30	20.75	19.51	20.47	20.00	19.70	20.20	18.05	19.69	19.16	20
29	165	163.2	-1.8	1.028	1.029	0.001	23.47	21.40	-2.07	23.34	21.35	-1.99	23.20	23.40	23.80	22.72	23.31	24.00	20.60	22.00	21.60	21.89	20.59	21.58	0
30	166.6	165.8	-0.8	1.021	1.021	0	22.73	27.00	4.27	22.41	21.50	-0.92	22.20	23.20	22.80	22.22	22.57	22.45	27.10	26.80	27.10	21.32	21.37	21.80	0
31	166.8	165.8	-1	1.028	1.029	0.001	24.77	24.07	-0.70	24.77	24.27	-0.49	24.50	24.30	25.50	24.53	24.89	24.88	25.40	23.30	23.50	24.33	23.85	24.64	3
32							22.20	20.87	-1.33	21.76	20.50	-1.26	22.30	22.30	22.00	21.18	21.88	22.21	19.90	21.80	20.90		20.17	20.83	16.9
Av	167.41	164.15	-3.25	1.021	1.024	0.003	22.03	21.89	-0.14	21.21	21.19	-0.02	21.96	22.37	22.24	21.27	21.13	21.24	21.88	21.88	22.14	21.26	21.20	21.15	9.09

Note: Highlighted ZOE2 measurements for participants #8 and #19 were statistical outliers and not include in statistical analysis

Table 5: Appendix A - Summary of Raw Data